ROUTING IN MOBILE AD HOC NETWORKS

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Outline

- Mobile Ad Hoc Network
- Background
- Expected properties of a MANET routing protocol
- Categorizing MANET routing protocols
- Examples of MANET routing protocols
- Evaluation of performance of the protocols
- Which one fits for which situation?
- Future global Internet structure and MANET

MANET

- A Mobile Ad Hoc Network (MANET) is built on the fly where a number of wireless mobile nodes work in cooperation without the engagement of any centralized access point or any fixed infrastructure

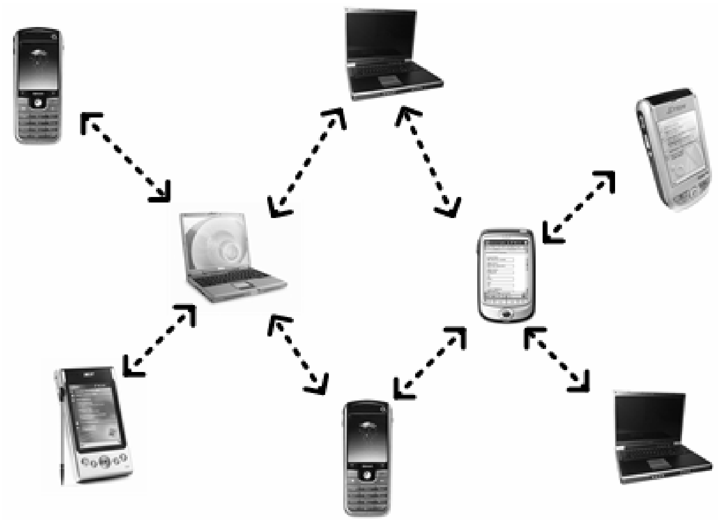
- Two nodes in such a network can communicate in a bidirectional manner if and only if the distance between them is at most the minimum of their transmission ranges

MANET (Contd.)

- When a node wants to communicate with a node outside its transmission range, a multi-hop routing strategy is used which involves some intermediate nodes

- Because of the movements of nodes, there is a constant possibility of changing of the topology of a MANET

MANET Example



Background

- From the advent of packet radio network up to today's MANET, the whole lifecycle of ad hoc networks can be categorized as
  - First generation
  - Second generation
  - Third generation

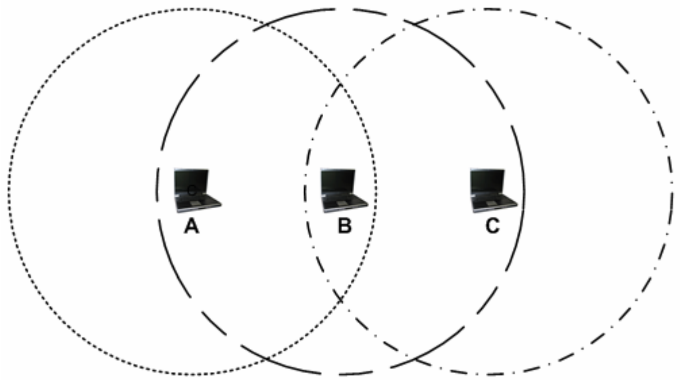
- Today's ad hoc networks are considered as the third generation networks

Background (Contd.)

- *First generation*
  - In 1972 they were called PRNET (Packet Radio Networks)
  - 1973, the Defense Advanced Research Projects Agency (DARPA) initiated research on the feasibility of using packet-switched radio communications to provide reliable computer communications
- *Second generation*
  - emerged in 1980s, when the ad-hoc network systems were further enhanced and implemented as a part of the SURAN (Survivable Adaptive Radio Networks) program.
- *Third generation*
  - 1990, the concept of commercial ad-hoc networks
  - At the same time, the idea of a collection of mobile nodes was proposed at several research conferences

Example 1

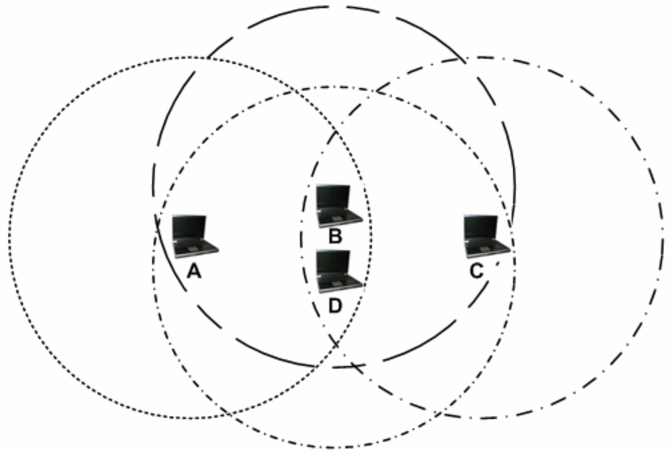
- In the figure, node A and node B are within the transmission ranges of each other. A and B are neighbors. Likewise, B and C are neighbors
- A and C are not neighbors as none of their transmission ranges covers other node
- Here, the neighbors can communicate directly and no routing is required. But, if A and C want to communicate with each other, they must seek help from node B, who can help them by forwarding their data packets



- Node A knows about B and C knows about B, so both A and C can use B as an intermediate node for their communications!
- Simple neighbor information could be used here

Example 2

- With the addition of node D, we have several options to exchange data between A and C. For example, a packet from A can take the path, A-B-C or A-D-C or A-D-B-C or A-B-D-C. This is where we need to employ efficient mechanism or logic for routing the packet in the best possible way



- The whole scenario gets even more complicated with the increase of the number of nodes in the network

- Only neighbor information is not enough in this case!

- Because of the mobility of nodes within the network, the scenario might become more and more complex

Expected Properties of Routing Protocol (RP)

- *Distributed:* A routing protocol for MANET should be distributed in manner in order to increase its reliability
- *Unidirectional links:* Wireless medium may cause a wireless link to be opened in unidirection only due to physical factors. It may not be possible to communicate bi-directionally
- *Power-efficient:* It should be power efficient
- *Security:* The routing protocol should consider its security (based on the application at hand)
- *Hybrid nature:* Hybrid protocols, which combine the benefits of different routing protocols can be preferred in many cases
- *QoS:* A routing protocol should be aware of Quality of Service (QoS), so that a real time application might rely on it

Categorizing MANET RPs

- *Broadly classified into two major categories*
  - Proactive Routing Protocols
  - Reactive Routing Protocols
- *Other Category*
  - Hybrid Routing Protocols (combination of proactive and reactive features of routing protocols)
- *Based on the method of delivery of packets*
  - Unicast Routing Protocols
  - Multicast Routing Protocols
- *Multicast routing protocols could be classified into*
  - Tree Based Multicast Protocols
  - Mesh Based Multicast Protocols

Proactive Routing Protocols

- Proactive protocols continuously learn the topology of the network by exchanging topological information among the network nodes
- The main concern regarding using a proactive routing protocol is; if the network topology changes too frequently, the cost of maintaining the network might be very high. Moreover, if the network activity is low, the information about the actual topology might even not be used and in such a case, the investment with such limited transmission ranges and energies is lost, which might result in a shorter lifetime of the network than that is expected
- Proactive protocols are sometimes called as **Table-Driven** routing protocols

Reactive Routing Protocols

- The reactive routing protocols on the other hand, are based on some sort of query-reply dialog. Reactive protocols proceed for establishing route (s) to the destination only when the need arises or on demand basis

- They do not need periodic transmission of topological information of the network; hence, they primarily seem to be resource conserving protocols

- Reactive protocols are also known as **On-Demand** routing protocols

Hybrid Routing Protocols

- Often reactive or proactive feature of a particular routing protocol might not be enough; instead a mixture might yield better solution. Hence, in the recent days, several hybrid protocols are also proposed

- The hybrid protocols include some of the characteristics of proactive protocols and some of the characteristics of reactive protocols

MANET Routing Protocols at a Glance

MANET Routing Protocols

- **Proactive (Table-Driven)**
  - DSDV
  - WRP
  - CGSR
  - GSR
  - FSR
  - HSR
  - ZHLS
  - LANMAR
  - OLSR
- **Reactive (On-Demand)**
  - ABR
  - SSA
  - TORA
  - CBRP
  - DSR
  - AODV
- **Hybrid**
  - DHAR
  - ADV
  - ZRP
  - SHARP
  - NAMP
- **Location-Aware, Geographic, and Other Routing Protocols**
  - GEDIR
  - LAR
  - GPSR
  - GeoGRID
  - GRA
  - LBM
  - MCEDAR
  - AMRIS
  - ABAM
  - MAODV
  - DDM
  - ODMRP
  - ADMR
  - AMRoute
  - DCMP
  - PLBM

DSDV [Proactive]

- Dynamic Destination-Sequenced Distance-Vector (DSDV) is based on the Bellman-Ford routing algorithm with some modifications
- In this routing protocol, each mobile node keeps a routing table.
- Each of the routing table contains the list of all available destinations and the number of hops to each
- Each table entry is tagged with a sequence number which is originated by the destination node
- Periodic transmissions of updates of the routing tables help maintaining the topology information of the network

DSDV (Contd.)

- If there is any new significant change for the routing information, the updates are transmitted immediately. So, the routing-information updates might either be periodic or event-driven
- DSDV requires each mobile node in the network to advertise its own routing table to its current neighbors.
- The advertisement is done either by broadcasting or by multicasting. By the advertisements, the neighboring nodes can know about any change that has occurred in the network due to the movements of nodes

DSDV (Contd.)

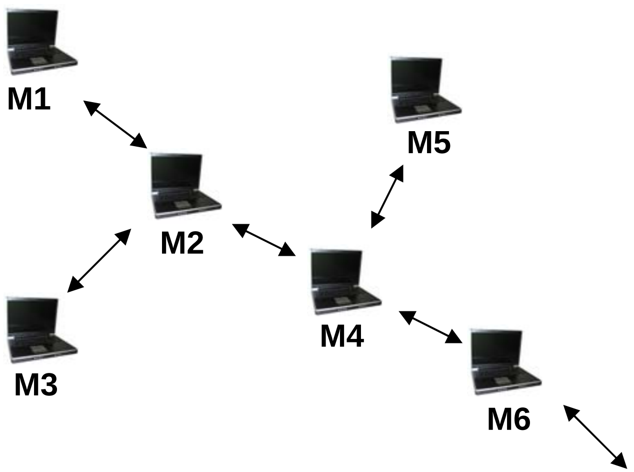
- The routing updates could be sent in two ways:
  - *Full dump:* the entire routing table is sent to the neighbors
  - *Incremental Update:* only the entries that require changes are sent
- Full dump is transmitted relatively infrequently when no movement of nodes occur. The incremental updates could be more appropriate when the network is relatively stable so that extra traffic could be avoided
- But, when the movements of nodes become frequent, the sizes of the incremental updates become large and approach the network protocol data unit (NPDU). Hence, in such a case, full dump could be used

DSDV (Contd.)

- Each of the route update packets also has a sequence number assigned by the transmitter. For updating the routing information in a node, the update packet with the highest sequence number is used

- Each node waits up to certain time interval to transmit the advertisement message to its neighbors so that the latest information with better route to a destination could be informed to the neighbors

DSDV Example



Forwarding Table of Node M2

Destination	Next Hop	Metric	Sequence Number	Install	Flags	Stable_data
M1	M1	1	S593_M1	T001_M2	-	Ptrl_M1
M2	M2	0	S983_M2	T001_M2	-	Ptrl_M2
~~M3~~	~~M3~~ M4	~~1~~ 3	~~S193_M3~~	~~T002_M2~~	~~-~~	~~Ptrl_M3~~
M4	M4	1	S233_M4	T001_M2	-	Ptrl_M4
M5	M4	2	S243_M5	T001_M2	-	Ptrl_M5
M6	M4	2	S053_M6	T002_M2	-	Ptrl_M6

Advertised Route Table of M2

Destination	Metric	Sequence Number
M1	1	S593_M1
M2	0	S983_M2
M3	~~1~~ 3	S193_M3
M4	1	S233_M4
M5	2	S243_M5
M6	2	S053_M6

If M3 changes its position, only the entry for M3 needs to be changed in the tables

WRP [Proactive]

- Wireless Routing Protocol (WRP) belongs to the general class of path-finding algorithms, defined as the set of distributed shortest-path algorithms that calculate the paths using information regarding the length and second-to-last hop of the shortest path to each destination

- WRP reduces the number of cases in which a temporary routing loop can occur. For the purpose of routing, each node maintains four things
  - A Distance Table
  - A Routing Table
  - A Link Cost Table
  - A Message Retransmission List (MRL)

WRP (Contd.)

- The distance table of node *x* contains the distance of each destination node *y* via each neighbor *z* of *x* and the predecessor node reported by *z*
- The routing table of node *x* is a vector with an entry for each known destination *y* which specifies
  - The identifier of the destination *y*
  - The distance to the destination *y*
  - The predecessor of the chosen shortest path to *y*
  - The successor of the chosen shortest path to *y*
  - A tag to identify whether the entry is a simple path, a loop or invalid
  - Storing predecessor and successor in the table is beneficial to detect loops and to avoid count-to-infinity problems

WRP (Contd.)

- The link-cost table of *x* lists the cost of relaying information through each neighbor *z*, and the number of periodic update periods that have elapsed since node *x* received any error-free message from *z*
- The message retransmission list (MRL) contains information to let a node know which of its neighbors has not acknowledged its update message and to retransmit update message to that neighbor
- WRP uses periodic update message transmissions to the neighbors of a node

CGSR [Proactive]

- CGSR (Cluster-head Gateway Switch Routing) considers a clustered mobile wireless network instead of a 'flat' network

- For structuring the network into separate but interrelated groups, cluster heads are elected using a cluster head selection algorithm

- CGSR uses DSDV protocol as the underlying routing scheme

CGSR (Contd.)

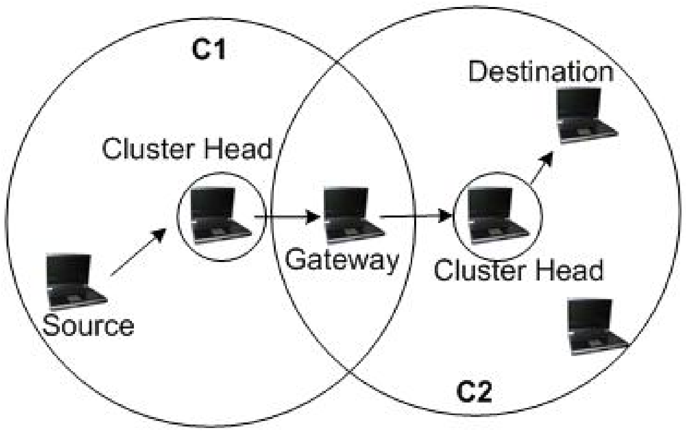
- But, it modifies DSDV by using a hierarchical cluster-head-to-gateway routing approach to route traffic from source to destination

- *Gateway Node:* Gateway nodes are nodes that are within communication ranges of two or more cluster heads

- A packet sent by a node is first sent to its cluster head, and then the packet is sent from the cluster head to a gateway to another cluster head, and so on until the cluster head of the destination node is reached

- The packet is then transmitted to the destination from its own cluster head

CGSR Example



Each node keeps a '*cluster member table*' where it stores the destination cluster head for each mobile node in the network

GSR [Proactive]

- In Global State Routing (GSR), nodes exchange vectors of link states among their neighbors during routing information exchange. Based on the link state vectors, nodes maintain a global knowledge of the network topology and optimize their routing decisions locally

- Functionally this protocol is similar to DSDV but it improves DSDV in the sense that, it avoids flooding of routing messages

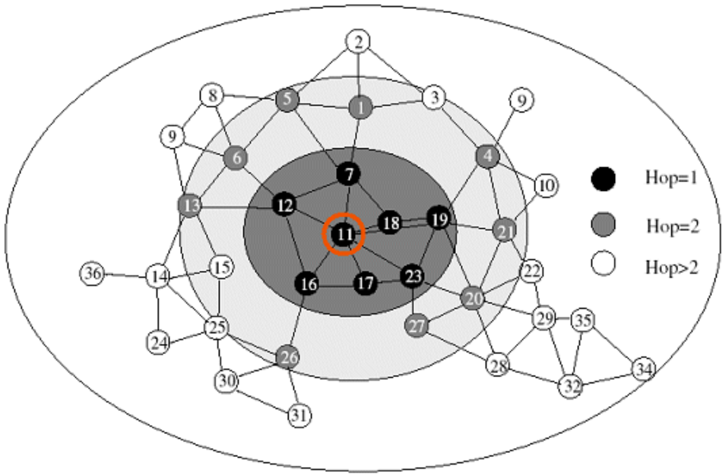
GSR (Contd.)

- Each node maintains one list and three tables
  - A Neighbor List
    - List of neighbor nodes
  - A Topology Table
    - Each entry in the topology table has two parts
      - One is the link state information reported by destination y
      - The other is the timestamp indicating the time node y has generated this link state information
  - A Next Hop Table
    - Contains next hop node's identity towards destination
  - A Distance Table
    - Keeps the distance from source to destination

FSR [Proactive]

- Fisheye State Routing is built on top of GSR
- It uses a special structure of the network called the '*fisheye*'
- The basic idea is that, each update message does not contain information about all nodes. Instead of that, it contains update information about the nearer nodes more frequently than that of the farther nodes
- Hence, each node can have accurate and exact information about its own neighboring nodes

FSR (Contd.)



- The *scope* of fisheye is defined as the set of nodes that can be reached within a given number of hops from a particular center node
- In the figure, we have shown three scopes with one, two, and three hops. The center node has the most accurate information about all nodes in the white circle and so on. Each circle contains the nodes of a particular hop from a center node

HSR [Proactive]

- Hierarchical State Routing (HSR) combines dynamic, distributed multilevel hierarchical clustering technique with an efficient location management scheme

- This protocol partitions the network into several clusters where each elected cluster head at the lower level in the hierarchy becomes member of the next higher level

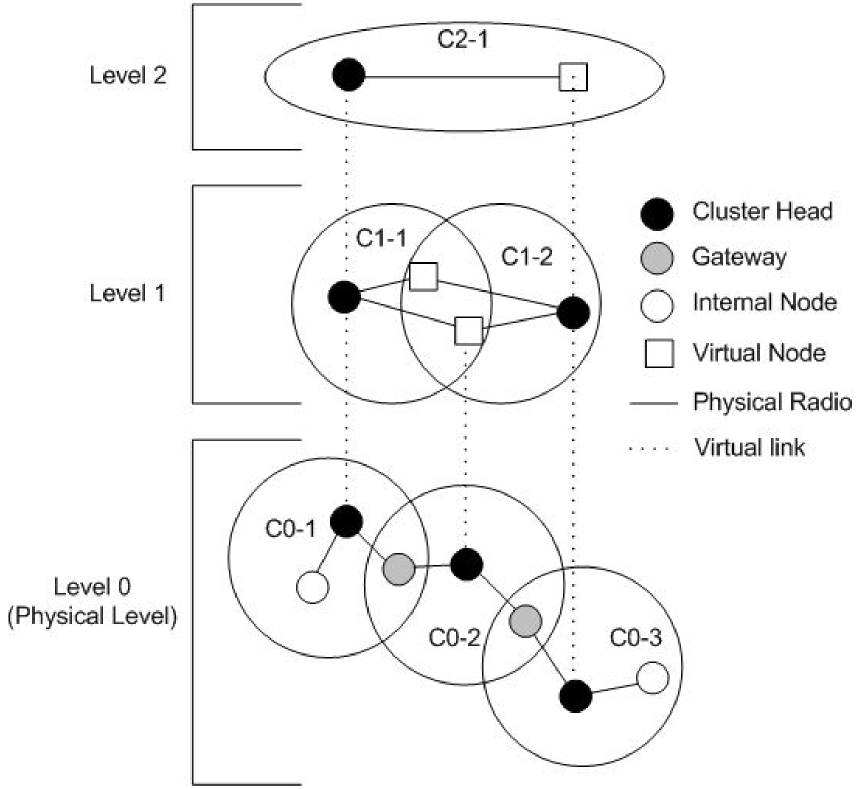
HSR (Contd.)

- The basic idea of HSR is that, each cluster head summarizes its own cluster information and passes it to the neighboring cluster heads using gateways

- After running the algorithm at any level, any node can flood the obtained information to its lower level nodes

- The hierarchical structure used in this protocol is efficient enough to deliver data successfully to any part of the network

HSR (Contd.)



Hierarchical Structure used in HSR Protocol

ZHLS [Proactive]

- In Zone-Based Hierarchical Link State Routing Protocol (ZHLS) protocol , the network is divided into non-overlapping zones as in cellular networks

- Each node knows the node connectivity within its own zone and the zone connectivity information of the entire network

- The link state routing is performed by employing two levels
  - Node level
  - Global zone level

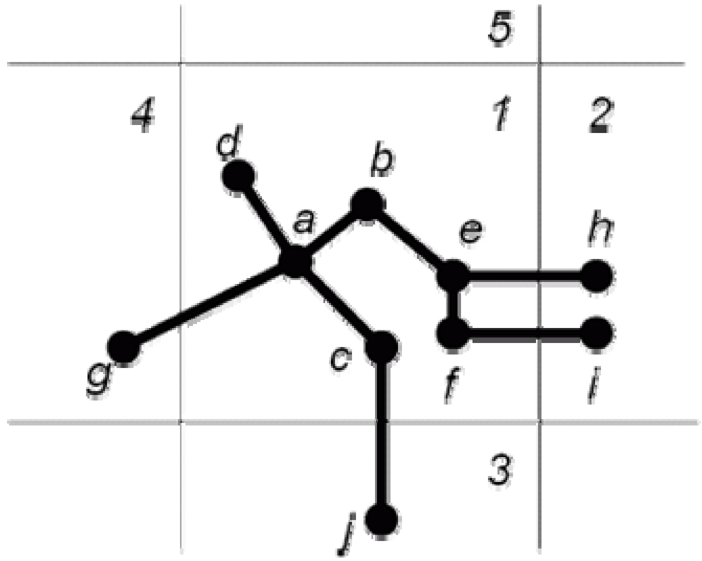
* Zone's information for a node is distributed

ZHLS (Contd.)

- ZHLS does not have any cluster head in the network like other hierarchical routing protocols. The zone level topological information is distributed to all nodes. Since only zone ID and node ID of a destination are needed for routing, the route from a source to a destination is adaptable to changing topology

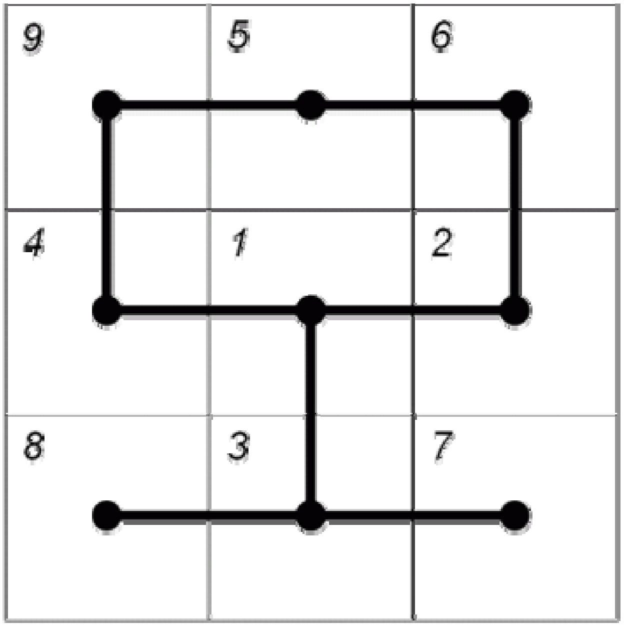
- The zone ID of the destination is found by sending one location request to every zone

ZHLS Topology



- node level (low level topology)
  - A node level topology tells how nodes of a zone are connected to each other. A virtual link between two zones exists when at least 1 node of a zone is connected to another zone in a different zone.

ZHLS Topology (Contd.)



- zone level (high level topology)
  - A zone level topology tells how zone are connected to each other. The zone level topologie is distributed to all nodes.

LANMAR [Proactive]

- Landmark Ad Hoc Routing (LANMAR) combines the features of Fisheye State Routing (FSR) and Landmark Routing. It uses the concept of *landmark* from Landmark Routing which was originally developed for fixed wide area networks

- *Landmark:* A *landmark* is defined as a router whose neighbor routers within a certain number of hops contain routing entries for that router

LANMAR (Contd.)

- Using this concept for the nodes in the MANET, LANMAR divides the network into several pre-defined logical subnets, each with a pre-selected landmark

- All nodes in a subnet are assumed to move as a group, and they remain connected to each other via Fisheye State Routing (FSR)

- LANMAR could be regarded as an extension of FSR which exploits group mobility by summarizing the routes to the group members with a single route to a landmark

OLSR [Proactive]

- Optimized Link State Routing protocol inherits the stability of link state algorithm. Usually in a pure link state protocol, all the links with neighbor nodes are declared and are flooded in the entire network. But, OLSR is an optimized version of a pure link state protocol designed for MANET

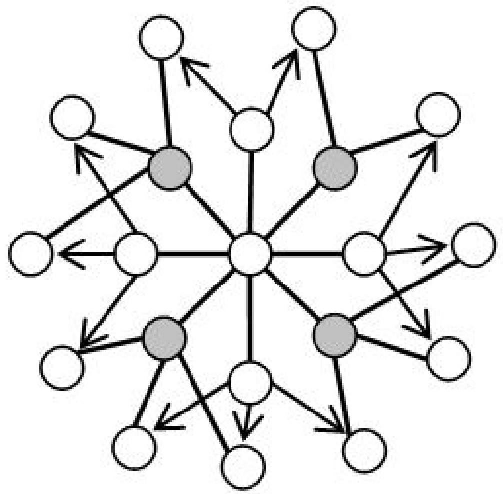
- This protocol performs hop by hop routing, that is; each node in the network uses its most recent information to route a packet.

- Hence, even when a node is moving, its packets can be successfully delivered to it, if its speed is such that its movements could at least be followed in its neighborhood

OLSR (Contd.)

- The optimization in the routing is done mainly in two ways
  - It reduces the size of control packets for a particular node by declaring only a subset of links with the node's neighbors who are its multipoint relay selectors, instead of all links in network
  - It minimizes flooding of control traffic by using only the selected nodes to disseminate information in the network. As only MultiPoint Relays (MPRs) of a node can retransmit its broadcast messages, it significantly reduces the no. of retransmissions in a flooding procedure

OLSR MPRs



Multi**P**oint **R**elays (MPRs) are in gray color

The transmitting node is shown at the center of the sample structure

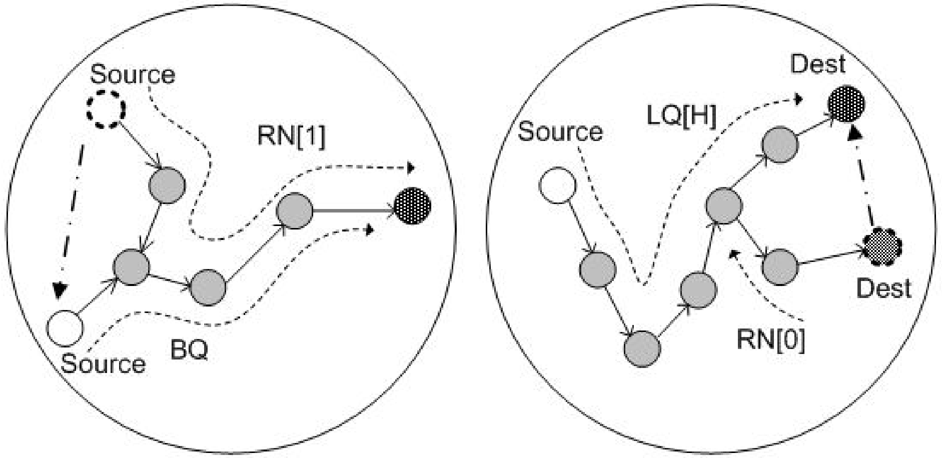
ABR [Reactive]

- Associativity-Based Routing (ABR) protocol defines a new type of routing metric for mobile ad hoc networks. This routing metric is termed as *degree of association stability*
- In this routing protocol, a route is selected based on the degree of association stability of mobile nodes
- Each node periodically generates beacon to announce its existence
- Upon receiving the beacon message a neighbor node updates its own associativity table. For each beacon received, the associativity tick of the receiving node with the beaconing node is increased

ABR (Contd.)

- A high value of associativity tick for any particular beaconing node means that the node is relatively static
- Associativity tick is reset when any neighboring node moves out of the neighborhood of any other node
- It has three phases for routing operation
  - Route discovery
  - Route reconstruction
  - Route deletion

ABR Example



- The route discovery phase is done by a broadcast query and await-reply (BQREPLY) cycle

- When a source node wants to send message to a destination, it sends the query. All other nodes receiving the query append their addresses and their associativity ticks with their neighbors along with QoS (Quality of Service) information to the query packet

ABR Example (Contd.)

- A downstream node erases its immediate upstream node's associativity tick entries and retains only the entry concerned with itself and its upstream node

- This process continues and eventually the packet reaches the destination. On receiving the packet with the associativity information, the destination chooses the best route and sends the REPLY packet using that path. If there are multiple paths with same overall degree of association stability, the route with the minimum number of hops is selected

ABR Example (Contd.)

- Route reconstruction is needed when any path becomes invalid or broken for the mobility or failure of any intermediate node. If a source or upstream node moves, a route notification (RN) message is used to erase the route entries associated with downstream nodes

- When the destination node moves, the destination's immediate upstream node erases its route. A localized query (LQ[H]) process, where H refers to the hop count from the upstream node to the destination, is initiated to determine whether the node is still reachable or not. Route deletion broadcast is done if any discovered route is no longer needed

SSA [Reactive]

- Signal Stability-Based Adaptive (SSA) Routing Protocol focuses on obtaining the most stable routes through an ad hoc network

- The protocol performs on-demand route discovery based on signal strength and location stability. Based on the signal strength, SSA detects weak and strong channels in the network

- SSA can be divided into two cooperative protocols
  - Dynamic Routing Protocol (DRP)
  - Static Routing Protocol (SRP)

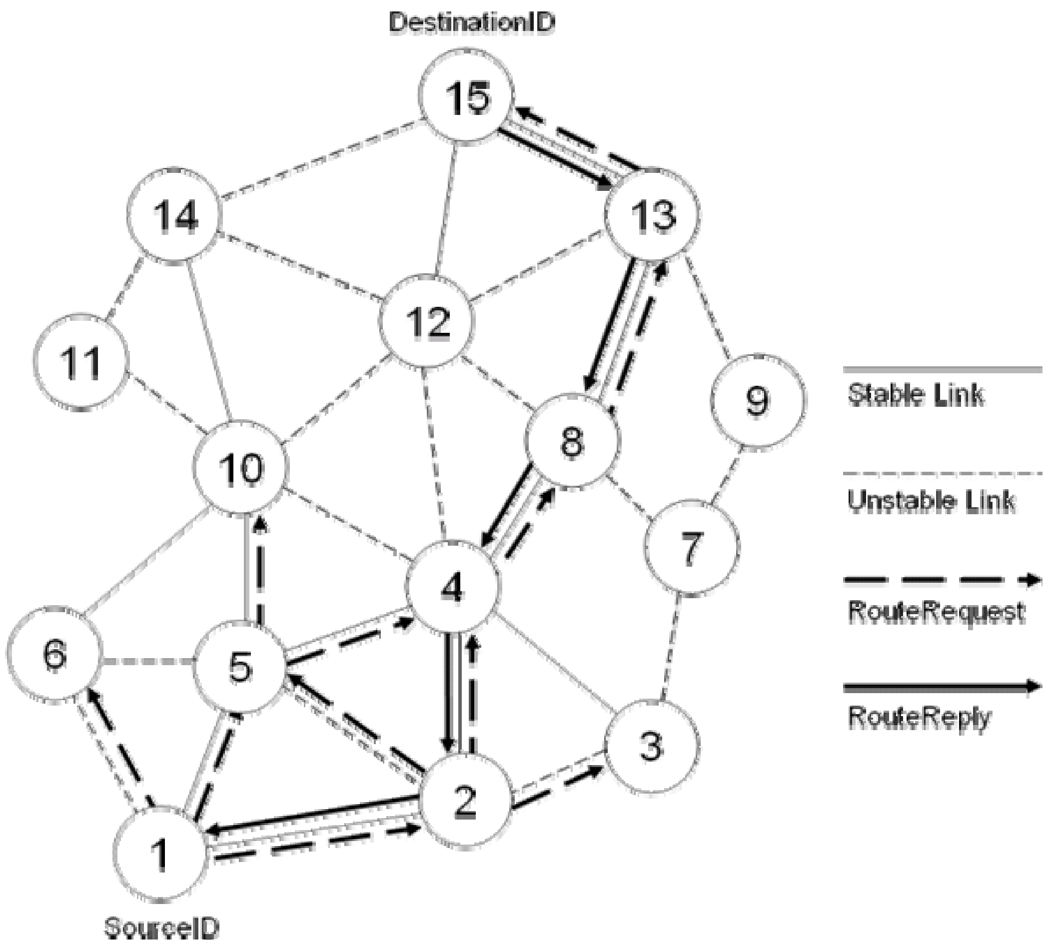
SSA (Contd.)

- DRP uses two tables
  - Signal Stability Table (SST)
  - Routing Table (RT)
- SST stores the signal strengths of the neighboring nodes obtained by periodic beacons from the link layer of each neighboring node. These signal strengths are recorded as weak or strong
- DRP receives all the transmissions and after processing, it passes those to the SRP. SRP passes the packet to the node’s upper layer stack if it is the destination. Otherwise, it looks for the destination in routing table and forwards the packet. If there is no entry in the routing table for that destination, it initiates the route finding process

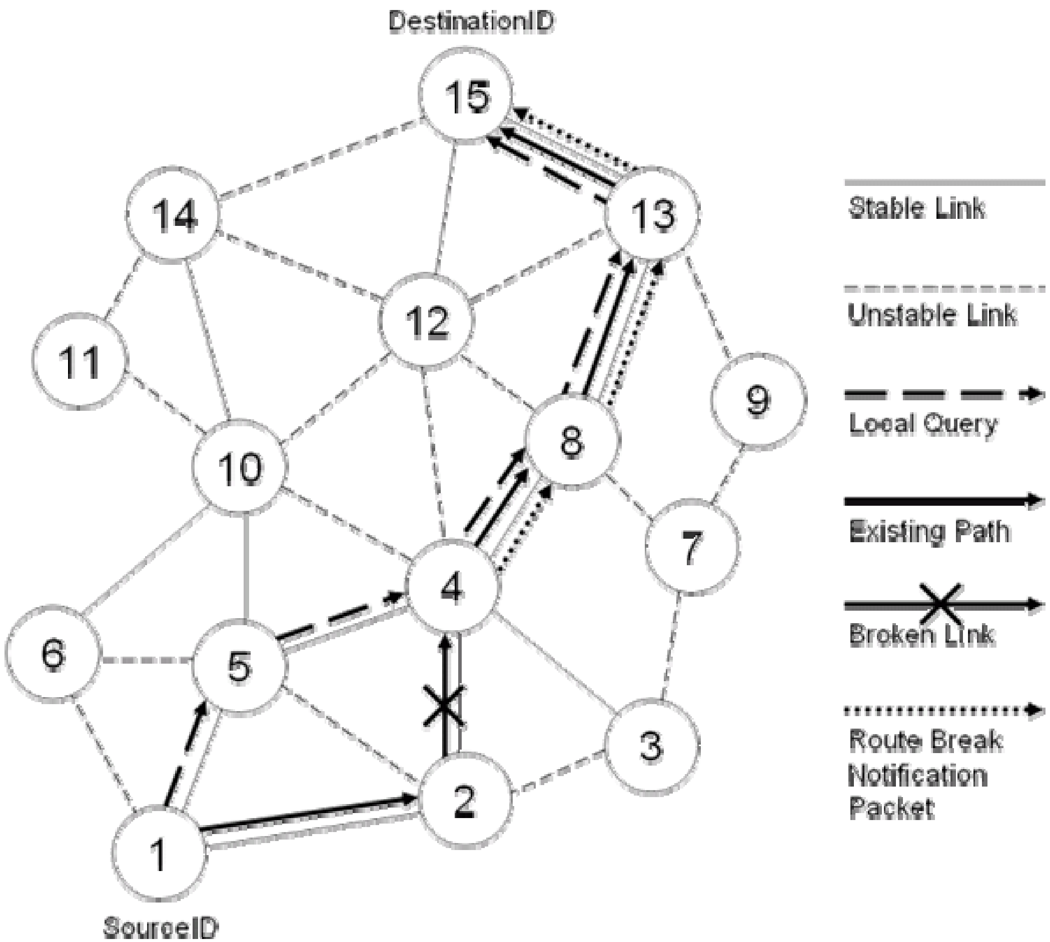
SSA (Contd.)

- Route request packets are forwarded to the neighbors using the strong channels. The destination, after getting the request, chooses the first arriving request packet and sends back the reply
- The DRP reverses the selected route and sends a route-reply message back to the initiator of route-request
- The DRPs of the nodes along the path update their routing tables accordingly
- In case of a link failure, the intermediate nodes send an error message to the source indicating which channel has failed. The source in turn sends an erase message to inform all nodes about the broken link and initiates a new route-search process to find a new path to the destination

SSA Route Establishment



SSA Route Maintenance



TORA [Reactive]

- Temporally Ordered Routing Algorithm (TORA) is a reactive routing protocol with some proactive enhancements where a link between nodes is established creating a Directed Acyclic Graph (DAG) of the route from the source node to the destination. This protocol uses a "*link reversal*" model in route discovery
- A route discovery query is broadcasted and propagated throughout the network until it reaches the destination or a node which has information about how to reach the destination
- TORA defines a parameter, termed *height*
- *Height* is a measure of the distance of the responding node's distance up to the required destination node

TORA (Contd.)

- In the route discovery phase, this (Height) parameter is returned to the querying node

- As the query response propagates back, each intermediate node updates its TORA table with the route and *height* to the destination node

- The source node then uses the *height* to select the best route towards the destination. This protocol has an interesting property that it frequently chooses the most convenient route, rather than the shortest route. For all these attempts TORA tries to minimize the routing management traffic overhead

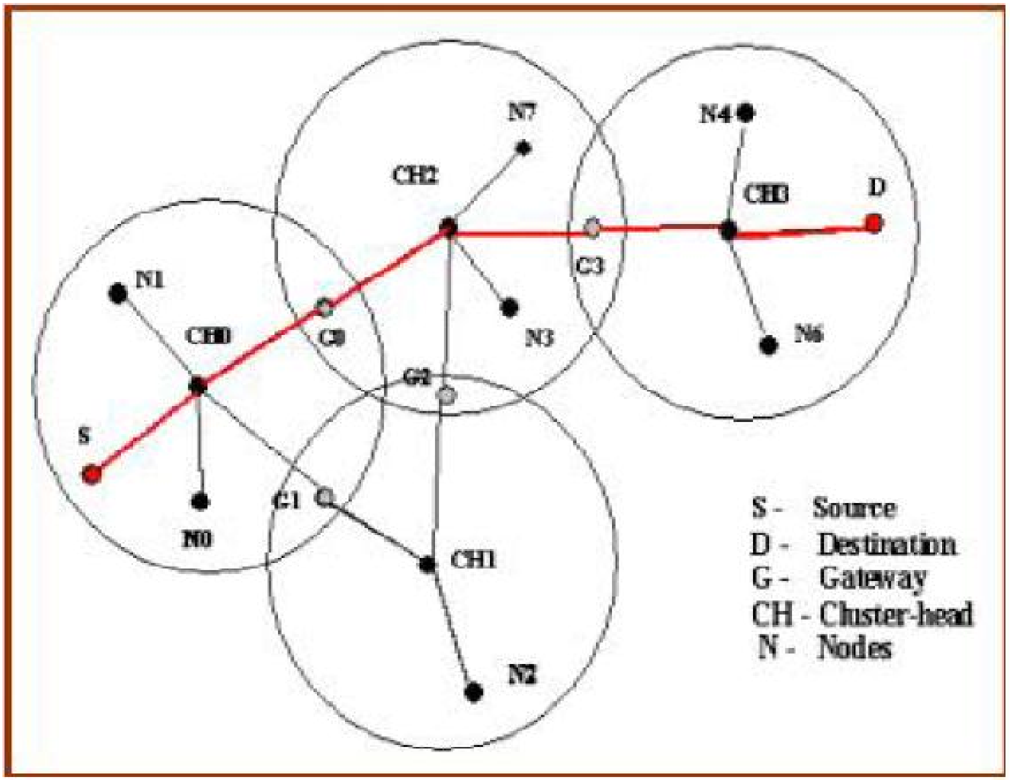
CBRP [Reactive]

- Cluster Based Routing Protocol (CBRP) is an on-demand routing protocol, where the nodes are divided into clusters
- For cluster formation, the following algorithm is employed
  - When a node comes up in the network, it has the *undecided* state
  - The first task of this node is to start a timer and to broadcast a HELLO message
  - When a cluster-head receives this HELLO message, it replies immediately with a triggered HELLO message. After that, when the node receives this answer, it changes its state into the *member* state

CBRP (Contd.)

- But when the node gets no message from any cluster-head, it makes itself as a cluster-head, but only when it has bidirectional link to one or more neighbor nodes
- Otherwise, when it has no link to any other node, it stays in the undecided state and repeats the procedure with sending a HELLO message again
- Each node has a neighbor table. For each neighbor, the node keeps the status of the link and state of the neighbor in the neighbor table
- A cluster head keeps information about all of its members in the same cluster. It also has a cluster adjacency table which provides information about the neighboring clusters

CBRP Topology



DSR [Reactive]

- Dynamic Source Routing (DSR) allows nodes in the MANET to dynamically discover a source route across multiple network hops to any destination

- In this protocol, the mobile nodes are required to maintain route caches or the known routes. The route cache is updated when any new route is known for a particular entry in the route cache

- Routing in DSR is done using two phases
  - route discovery
  - route maintenance

DSR (Contd.)

- When a source node wants to send a packet to a destination, it first consults its route cache to determine whether it already knows about any route to the destination or not
- If already there is an entry for that destination, the source uses that to send the packet. If not, it initiates a route request broadcast
- This request includes the destination address, source address, and a unique identification number. Each intermediate node checks whether it knows about the destination or not. If the intermediate node doesn't know about the destination, it again forwards the packet and eventually this reaches the destination

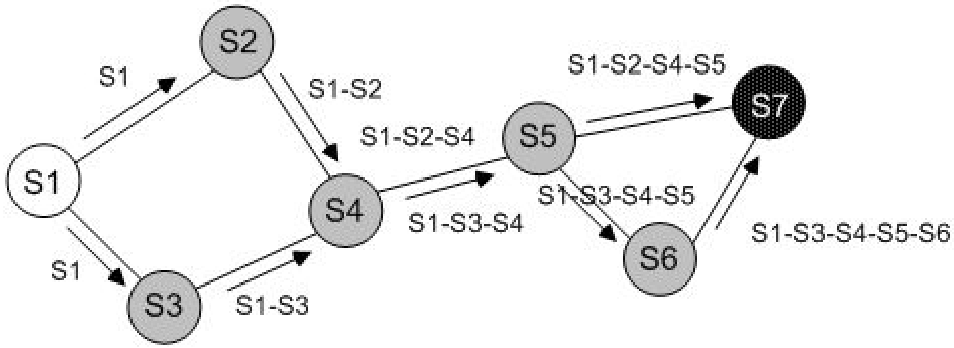
DSR (Contd.)

- A node processes the route request packet only if it has not previously processed the packet and its address is not present in the route record of the packet

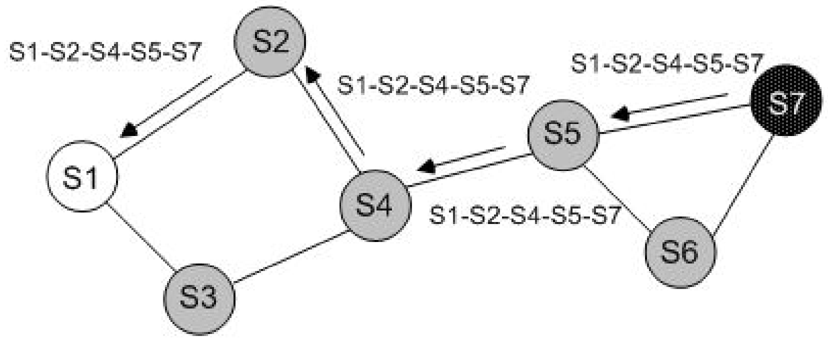
- A route reply is generated by the destination or by any of the intermediate nodes when it knows about how to reach the destination

- Next figures show the operational method of the dynamic source routing protocol

DSR Example



Route discovery



Using route records to send the route reply

AODV [Reactive]

- Ad Hoc On-Demand Distance Vector Routing (AODV) is basically an improvement of Dynamic Destination-Sequenced Distance-Vector routing protocol

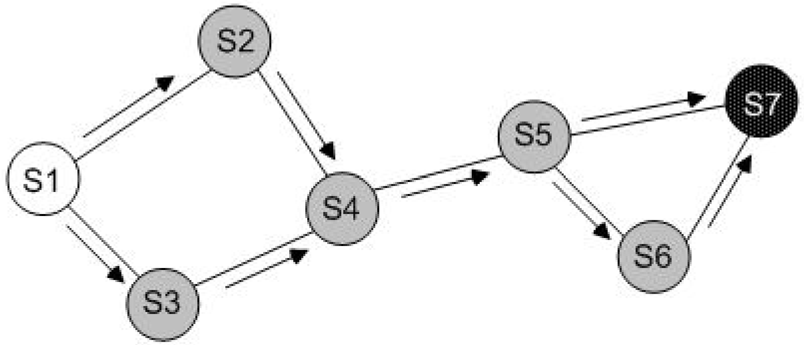
- But, AODV is a reactive routing protocol instead of proactive. It minimizes the number of broadcasts by creating routes based on demand, which is not the case for DSDV

- When any source node wants to send a packet to a destination, it broadcasts a route request (RREQ) packet. The neighboring nodes in turn broadcast the packet to their neighbors and the process continues until the packet reaches the destination

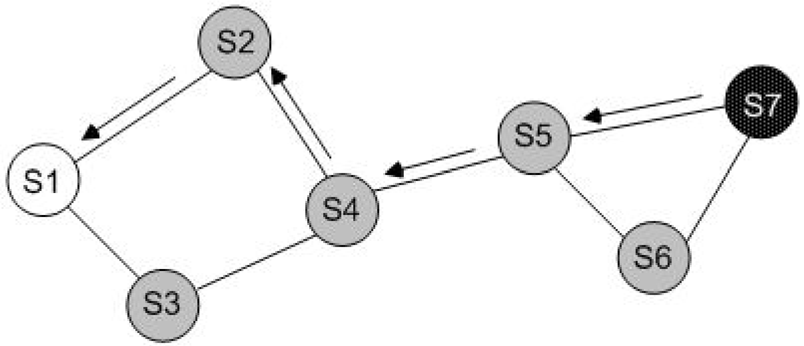
AODV (Contd.)

- During the process of forwarding the route request, intermediate nodes record the address of the neighbor from which the first copy of the broadcast packet is received
- This record is stored in their route tables, which helps for establishing a reverse path. If additional copies of the same RREQ are later received, these packets are discarded
- The reply is sent using the reverse path. For route maintenance, when a source node moves, it can reinitiate route discovery
- If any intermediate node moves within a particular route, the neighbor of that node can detect the link failure and sends a link failure notification to its upstream neighbor. This process continues until the failure notification reaches the source node
- Based on the received information, the source might decide to reinitiate the route discovery phase

AODV Example



Source node broadcasting route request



Route reply is sent to the source using the reverse path

DHAR [Hybrid]

- Dual-Hybrid Adaptive Routing uses the Distributed Dynamic Cluster Algorithm (DDCA)

- The idea of DDCA is to dynamically partition the network into some non-overlapping clusters of nodes consisting of one parent and zero or more children

- Routing is done with a dynamic two level hierarchical strategy consisting of optimal and least-overhead table-driven algorithms operating at each level

- DHAR implements a proactive least-overhead level-2 routing protocol in combination with a dynamic binding protocol to achieve its hybrid characteristics

DHAR (Contd.)

- The level-2 protocol requires that one node generates an update on behalf of its cluster. When a level-2 update is generated, it must be flooded to all the nodes in each neighboring cluster. Level-2 updates are not transmitted beyond the neighboring clusters

- The node with the lowest node ID in each cluster is designated to generate level-2 updates

- The binding process is similar to a reactive route discovery process; however, a priori knowledge of clustered topology makes it significantly more efficient and simpler to accomplish the routing

DHAR (Contd.)

- To send packets to the desired destination, a source node uses the dynamic binding protocol to discover the current cluster ID associated with the destination. Once determined, this information is maintained in the dynamic cluster binding cache at the source node

- The dynamic binding protocol utilizes knowledge of the level-2 topology to efficiently broadcast a binding request to all the clusters. This is achieved using reverse path forwarding with respect to the source cluster

ADV [Hybrid]

- Adaptive Distance Vector (ADV) routing protocol is a distance vector routing algorithm that exhibits some on-demand features by varying the frequency and the size of routing updates in response to the network load and mobility patterns

- This protocol has both the benefits of proactive and reactive routing protocols. ADV uses an adaptive mechanism to mitigate the effect of periodic transmissions of the routing updates which basically relies on the network load and mobility conditions

ADV (Contd.)

- To reduce the size of routing updates, ADV advertises and maintains routes for the active receivers only. A node is considered active if it is the receiver of any currently active connection. There is a *receiver flag* in the routing entry which keeps the information about the status of a receiver whether it is active or inactive

- To send data, a source node broadcasts network-wide an *init-connection* control packet. All the other nodes turn on the corresponding *receiver flag* in their own routing tables and start advertising the routes to the receiver in future updates. When the destination node gets the *init-connection* packet, it responds to it by broadcasting a *receiver-alert* packet and becomes active

ADV (Contd.)

- To close a connection, the source node broadcasts network-wide an *end-connection* control packet indicating that the connection is to be closed. If the destination node has no additional active connection, it broadcasts a *non-receiver-alert* message

- If the *init-connection* and *receiver-alert* messages are lost, the source advertises the receiver's entry with its *receiver flag* set in all future updates. ADV also defines some other parameters like trigger meter, trigger threshold, and buffer threshold. These are used for limiting the network traffic based on the network's mobility pattern and network speed

ZRP [Hybrid]

- ZRP (Zone Routing Protocol) is suitable for wide variety of MANETs, especially for the networks with large span and diverse mobility patterns. In this protocol, each node proactively maintains routes within a local region which is termed as routing zone

- Route creation is done using a query-reply mechanism. For creating different zones in the network, a node first has to know who its neighbors are. A neighbor is defined as a node with whom direct communication can be established and that is, within one hop transmission range of a node. Neighbor discovery information is used as a basis for Intra-zone Routing Protocol (IARP)

ZRP (Contd.)

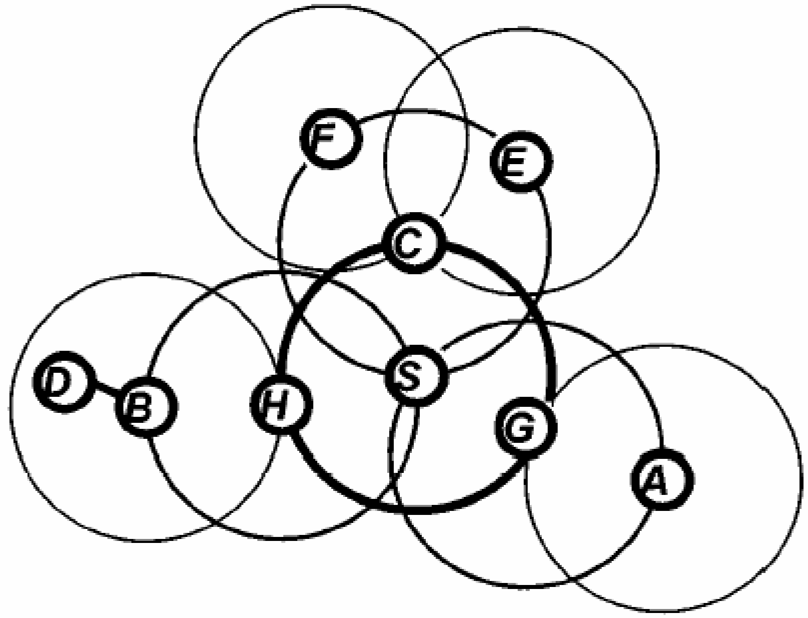
- Rather than blind broadcasting, ZRP uses a query control mechanism to reduce route query traffic by directing query messages outward from the query source and away from covered routing zones

- A *covered node* is a node which belongs to the routing zone of a node that has received a route query.

- During the forwarding of the query packet, a node identifies whether it is coming from its neighbor or not. If yes, then it marks all of its known neighboring nodes in its same zone as covered. The query is thus relayed till it reaches the destination. The destination in turn sends back a reply message via the reverse path and creates the route

ZRP Example (IntErzone Routing)

- S prepares to send data to D
- S checks if D is in its routing zone
- S send Route Query to its peripheral nodes G, H, C
- H sends to B, B sends forwarding path S-H-B-D
- Best route can be selected from many possible ones



SHARP [Hybrid]

- Sharp Hybrid Adaptive Routing Protocol combines the features of both proactive and reactive routing mechanisms

- SHARP adapts between reactive and proactive routing by dynamically varying the amount of routing information shared proactively

- This protocol defines proactive zones around some nodes

- The number of nodes in a particular proactive zone is determined by the node-specific zone radius. All nodes within the zone radius of a particular node become the member of that particular proactive zone for that node

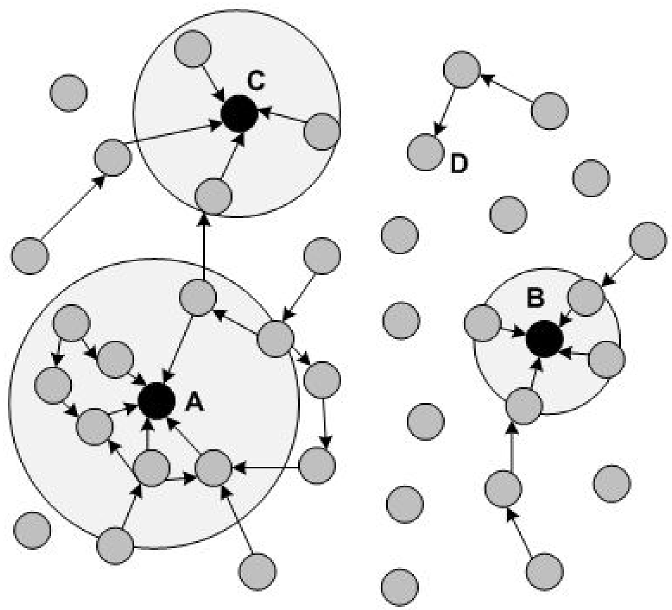
SHARP (Contd.)

- If for a given destination, a node is not present within a particular proactive zone, reactive routing mechanism (query-reply) is used to establish route to that node

- Proactive routing mechanism is used within the proactive zone. Nodes within the proactive zone maintain routes proactively only with respect to the central node

- In this protocol, proactive zones are created automatically if some destinations are **frequently addressed or sought within the network**. The proactive zones act as collectors of packets which forward the packets efficiently to the destination, once the packets reach any node at the zone vicinity

SHARP Structure in MANET



Proactive zones around the hot destinations in SHARP

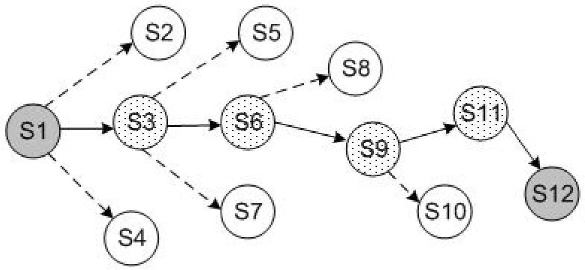
NAMP [Hybrid]

- Neighbor Aware Multicast Routing Protocol (NAMP) is a tree-based hybrid routing protocol which utilizes neighborhood information. The routes in the network are built and maintained using the traditional request and reply messages or on demand basis
- This hybrid protocol uses neighbor information of two-hops away for transmitting the packets to the receiver. If the receiver is not within this range, it searches the receiver using dominant pruning flooding method and forms a multicast tree using the replies along the reverse path
- There are mainly three operations addressed in NAMP
  - Multicast tree creation
  - Multicast tree maintenance
  - Joining and leaving of nodes from the multicast group

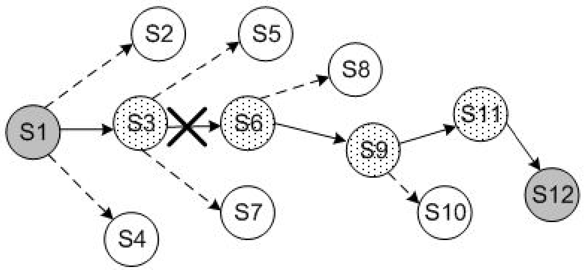
NAMP (Contd.)

- All the nodes in the network keep neighborhood information of up to two-hop away nodes. This neighborhood information is maintained using a proactive mechanism. Periodic *hello* packet is used for this. To create the multicast tree, the source node sends a *flood request* packet to the destination with data payload attached
- This packet is flooded in the network using dominant pruning method, which actually minimizes the number of transmissions in the network for a particular *flood request* packet. During the forwarding process of the packet, each node selects a forwarder and creates a secondary forwarder list (*SFL*)
- The secondary forwarder list (*SFL*) contains the information about the nodes those were primarily considered as possible forwarders but finally were not selected for that purpose. Each intermediate node uses the chosen forwarder to forward the packet but keeps the knowledge about other possible forwarders in *SFL*. Secondary forwarder list is used for repairing any broken route in the network

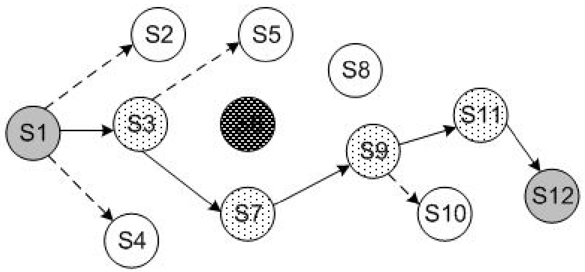
NAMP Example



Multicast tree creation



Broken route



Broken route recovery using secondary forwarding list

Other Routing Protocols

- There are some other routing protocols which do not rely on any traditional routing mechanisms, instead rely on the location awareness of the nodes
- Generally in traditional MANETs, the nodes are addressed only with their IP addresses.
- But, in case of location aware routing mechanisms, the nodes are often aware of their exact physical locations in the three-dimensional world.
- This capability might be introduced in the nodes using Global Positioning System (GPS) or with any other geometric methods.

Other Routing Protocols

- GPS is a worldwide, satellite based radio navigation system which consists of 24 satellites in six orbital planes. By connecting to the GPS receiver, a mobile node can know its current physical location
- Also sometimes the network is divided into several zones or geographic regions for making routing little bit easier
- Geocasting is basically a variant of the conventional multicasting where the nodes are considered under certain groups within particular geographical regions. In geocasting, the nodes eligible to receive packets are implicitly specified by a physical region; membership in a geocast group changes whenever a mobile node moves in or out of the geocast region

Other Routing Protocols

- **GEDIR** – GEographic DIstance Routing
- **LAR** – Location Aided Routing
- **GPSR** – Greedy Perimeter Stateless Routing
- **GeoGRID** – Geographical GRID
- **GRA** – Geographical Routing Algorithm
- **LBM** – Location-Based Multicast
- **MCEDAR** – Multicast Core Extraction Distributed Ad hoc Routing
- **AMRIS** – Ad hoc Multicast Routing protocol utilizing Increasing id-numberS
- **ABAM** – Associativity-Based Ad hoc Multicast
- **MAODV** – Multicast Ad hoc On-Demand Distance Vector
- **DDM** – Differential Destination Multicast
- **ODMRP** – On-Demand Multicast Routing Protocol
- **ADMR** – Adaptive Demand-driven Multicast Routing
- **AMRoute** – Ad hoc Multicast Routing
- **DCMP** – Dynamic Core based Multicast routing Protocol
- **PLBM** – Preferred Link Based Multicast

ETC.

Performance Criteria

- **Mobility Factors**
  - ***Velocity of Nodes:*** As there is no speed limitation of the wireless devices, high speed of nodes might affect the performance of many protocols. However, it is true that routing in a highly mobile MANET is a tough task
  - ***Direction of Mobility:*** It is a very common incident that, a node travels to a direction where the number of neighbor nodes is less or there is no neighbor node. This is called drifting away of a node from a MANET
    - In hard-state approach, the node explicitly informs all the other nodes in the MANET about its departure or movement from a position
    - In a soft-state approach, a time out value is used to detect the departure

Performance Criteria (Contd.)

- ***Group or Individual Mobility:*** MANETs are often categorized as Pure MANET and Military MANET. A military MANET can maintain a well defined chain of commands which is absent in case of a pure MANET
  - Two MANET protocols considered as good for supporting group mobility are LANMAR, developed by University of California at Los Angeles and OLSR, which is developed by the French National Institute for Research in Computer Science and Control (INRIA)
- ***Frequency of Changing of Mobility Model:*** Routing strategy could also vary depending on the mobility model of the MANET. The topology of an ad hoc network could definitely change over time. But, the key factor here is the change of overall mobility model in a fast or relatively slow fashion

Performance Criteria (Contd.)

- **Wireless Communications Factors**
  - ***Consumption of Power:*** Power is a valuable resource in wireless networking. Especially for routing, power is highly needed. According to an experiment by Kravets and Krishnan (1998), power consumption caused by networking related activities is approximately 10% of the overall power consumption of a laptop computer. This figure rises up to 50% in handheld devices

  - ***Bandwidth:*** For any type of wireless communications, bandwidth available for the network is a major concern. An efficient routing protocol should try to minimize the number of packet-transmissions or control overhead for the maintenance of the network

Performance Criteria (Contd.)

- ***Error Rate:*** Wireless communication is always susceptible to high error rate. Packet loss is a common incident. So, the routing strategies should be intelligent enough to minimize the error rate for smooth communications among the nodes

- ***Unidirectional Link:*** Sometimes it is convenient for a routing protocol to assume routes as unidirectional links

Performance Criteria (Contd.)

- **Security Issues**
  - ***Unauthorized Access:*** Security has recently become a major issue for ad hoc network routing. Most of the ad-hoc network routing protocols that are currently proposed lack security. A wireless network is more vulnerable than a wired network. So, based on the requirement, sometimes preventing unauthorized access to the network becomes the major concern
  - ***Accidental Association with Other Networks:*** Accidental associations between a node in one wireless network and a neighboring wireless network are just now being recognized as a security concern as enterprises confront the issue of overlapping networks. At the routing level it should be ensured that the nodes can recognize their own network

Performance Criteria (Contd.)

- **Other Factors**
  - ***Reliability of the Network:*** Reliability is sometimes defines as how efficiently a routing protocol can dispatch packets to the appropriate destinations. A routing protocol must be efficient enough to handle successful packet delivery so that an application may rely on it
  - ***Size of the Network:*** The overall network size could be a crucial factor. A routing protocol might be good for a small network but might not be fit for use in a large ad hoc network or vice-versa. For example, AODV, DSR, OLSR are some of the protocols suitable for relatively smaller networks while the routing protocols like TORA, LANMAR, ZRP are suitable for larger networks

Performance Criteria (Contd.)

- ***Quality of Service:*** In the real time applications, Quality of Service becomes a key factor for evaluating the performance of a routing protocol

- ***Timing:*** Regardless of the method of communication used, access time and tuning time must be considered. Tuning time is the measure of the amount of time each node spends in active mode. In the active mode a node consumes maximum power. So, minimizing the tuning time is one of the critical factors to conserve power

Which one fits for which situation?

- It is still a matter of debate whether the routing protocols for mobile ad hoc networks should be predicted based on the network overhead or the optimization of the network path

- Proactive routing protocols tend to provide lower latency than on-demand protocols because they try to maintain routes to all the nodes in the network all the time. But the drawback for such protocols is the excessive routing overhead transmitted that is periodic in nature without much consideration for the network mobility or load

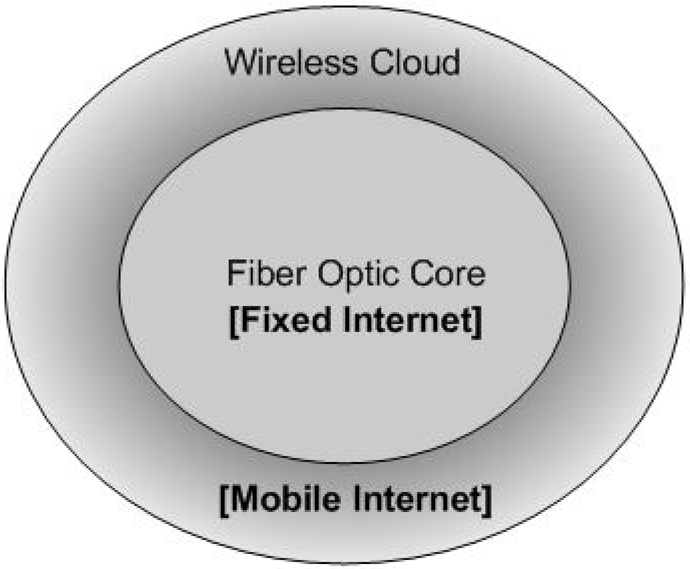
- On the other hand, though reactive protocols discover routes only when they are needed, they may still generate a huge amount of traffic when the network changes frequently

Which one fits for which situation?

- Hence, the answer to the debating point might be that, the mobility and traffic pattern of the network must play the key role for choosing an appropriate routing strategy for a particular network

- It is quite natural that, one particular solution cannot be applied for all sorts of situations and even if applied, might not be optimal in all cases. Often it is more appropriate to apply a hybrid protocol rather than a strictly proactive or reactive protocol as hybrid protocols often possess the advantages of both types of protocols

Future Global Internet Structure



Future Global Internet Structure

- The structure of the Internet that is used today is based mainly on wired communications. The emerging technologies like fiber optics based high speed wired networks will flourish in the near future. With this existing network of networks, semi-infrastructure and infrastructure-less wireless networks will also be used in abundance

- MANETs would definitely play an important role in the future Internet structure especially for the mobile Internet. Hence, in some cases, it might be necessary that the routing protocols of MANET work in perfect harmony with their wired counterparts. Considering different approaches of routing, a hybrid approach might be more appropriate for such scenarios

References

[1] Kahn, R. E., "The organization of computer resources into a packet radio network", IEEE Transactions on Communications, vol. COM-25, No. 1, Jan. 1977, pp. 169-178.

[2] Jubin, J. and Tornow, J. D., "The DARPA Packet Radio Network Protocols", Proceedings of the IEEE, Vol. 75, No. 1, Jan. 1987, pp. 21-32.

[3] Freebersyser, J. and Leiner, B., "A DoD Perspective on Mobile Ad Hoc Networks", Ad Hoc Networking, Ed. C. E. Perkins, Addison-Wesley, 2001, pp. 29-51.

[4] Yang, H., Luo, H., Ye, F., Lu, S., and Zhang, L., "Security in Mobile Ad Hoc Networks: Challenges and Solutions", IEEE Wireless Communications, February 2004, pp. 38-47.

[5] Deng, H., Li, W., and Agrawal, D. P., "Routing Security in Wireless Ad Hoc Networks", IEEE Communications Magazine, October 2002, pp. 70-75.

[6] Maihöfer, C., "A Survey of Geocast Routing Protocols", IEEE Communications Surveys & Tutorials. Vol. 6, No. 2, Q2 2004, pp. 32-42.

[7] Perkins, C. E. and Bhagwat, P., "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers", Proceedings of ACM SIGCOMM 1994, pp. 234-244.

[8] Cheng, C., Riley, R., Kumar, S. P. R., and Garcia-Luna-Aceves, J. J., "A Loop-Free Ex-tended Bellman-Ford Routing Protocol Without Bouncing Effect", ACM SIGCOMM Com-puter Communications Review, 1989, pp. 224-236.

[9] Murthy, S. and Garcia-Luna-Aceves, J. J., "An Efficient Routing Protocol for Wireless Net-works", Mobile Networks and Applications 1, 1996, pp. 183-197.

[10] Humblet, P. A., "Another Adaptive Distributed Shortest-Path Algorithm", IEEE Transac-tions on Communications, 39(6), 1991, pp. 995-1003.

References (Contd.)

[11] Rajagopalan, B. and Faiman, M., "A Responsive Distributed Shortest-Path Routing Algo-rithm Within Autonomous Systems", J. Internetworking:Res. and Exp. 2(1), 1991, pp. 51-69.

[12] Chiang, C.-C., Wu, H.-K., Liu, W., and Gerla, M. "Routing in Clustered Multihop, Mobile Wireless Networks with Fading Channel", Proceedings of IEEE SICON 1997, pp. 197-211.

[13] Chen, T.-W. and Gerla, M., "Global State Routing: A New Routing Scheme for Ad-hoc Wireless Networks", Proceedings of IEEE ICC 1998, pp. 171-175.

[14] Iwata, A., Chiang, C.-C., Pei, G., Gerla, M., and Chen, T.-W., "Scalable Routing Strategies for Ad Hoc Wireless Networks", IEEE Journal on Selected Areas in Communications, Vol. 17, No. 8, August 1999, pp. 1369-1379.

[15] Jao-Ng, M. and Lu, I-T., "A Peer-to-Peer Zone-Based Two-Level Link State Routing for Mobile Ad Hoc Networks", IEEE Journal on Selected Areas in Communications, Vol. 17, No. 8, August 1999, pp. 1415-1425.

[16] Pei, G., Gerla, M., and Hong, X., "LANMAR: Landmark Routing for Large Scale Wireless Ad Hoc Network with Group Mobility", First Annual Workshop on Mobile and Ad Hoc Networking and Computing 2000 (MobiHoc 2000), pp. 11-18.

[17] Tsuchiya, P. F., "The Landmark Hierarchy: A New Hierarchy for Routing in Very Large Networks", Computer Communication Review, Vol. 18, No. 4, August 1988, pp. 35-42.

[18] Jacquet, P., Mühlethaler, P., Clausen, T., Laouiti, A., Qayyum, A., and Viennot, L., "Opti-mized Link State Routing Protocol for Ad Hoc Networks", IEEE INMIC 2001, pp. 62-68.

[19] Toh, C.-K., "A Novel Distributed Routing Protocol to Support Ad-Hoc Mobile Computing", Proceedings of the 1996 IEEE 15th Annual International Phoenix Conference on Computers and Communications, 1996, pp. 480-486.

[20] Dube, R., Rais, C. D., Wang, K.-Y., and Tripathi, S. K., "Signal Stability-Based Adaptive Routing (SSA) for Ad Hoc Mobile Networks", IEEE Personal Communications, February 1997, pp. 36-45.

References (Contd.)

[21] Park, V. D. and Corson, M. S., "A highly adaptive distributed routing algorithm for mobile wireless networks", Proceedings of IEEE INFOCOM 1997, Volume 3, April, 1997, pp. 1405-1413.

[22] Jiang, M., Li, J., and Tay, Y. C., "Cluster Based Routing Protocol (CBRP)", IETF Draft, August 1999, available at http://tools.ietf.org/html/draft-ietf-manet-cbrp-spec-01

[23] Broch, J., Johnson, D. B., and Maltz, D. A., "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks", IETF Draft, October, 1999, available at http://tools.ietf.org/id/draft-ietf-manet-dsr-03.txt.

[24] Perkins, C. E., Royer, E. M., and Chakeres, I. D., "Ad Hoc On-Demand Distance Vector (AODV) Routing", IETF Draft, October, 2003, available at http://tools.ietf.org/html/draft-perkins-manet-aodvbis-00

[25] McDonald, A. B. and Znati, T., "A Dual-Hybrid Adaptive Routing Strategy for Wireless Ad-Hoc Networks", Proceedings of IEEE WCNC 2000, Volume 3, pp. 1125-1130.

[26] McDonald, A. B. and Znati, T., "A Mobility Based Framework for Adaptive Clustering in Wireless Ad-Hoc Networks", IEEE Journal on Selected Areas in Communicaitons, Special Issue on Ad-Hoc Networks, 17(8), August, 1999, pp. 1466-1487.

[27] Boppana, R. V. and Konduru, S. P., "An Adaptive Distance Vector Routing Algorithm for Mobile, Ad Hoc Networks", Proceedings of IEEE INFOCOM 2001, pp. 1753-1762.

[28] Haas, Z. J., Pearlman, M. R., and Samar, P., "The Zone Routing Protocol (ZRP) for Ad Hoc Networks", IETF draft, July 2002, available at http://tools.ietf.org/id/draft-ietf-manet-zone-zrp-04.txt

[29] Haas, Z.J., Pearlman, M.R., and Samar, P., "Intrazone Routing Protocol (IARP)," IETF Internet Draft, July 2002, available at http://tools.ietf.org/wg/manet/draft-ietf-manet-zone-ierp/draft-ietf-manet-zone-ierp-02-from-01.diff.txt

[30] Ramasubramanian, V., Haas, Z. J., and Sirer, E. G., "SHARP: A Hybrid Adaptive Routing Protocol for Mobile Ad Hoc Networks", Proceedings of ACM MobiHoc 2003, pp. 303-314.

References (Contd.)

[31] Pathan, A.-S. K., Alam, M. M., Monowar, M. M., and Rabbi, M. F., “An Efficient Routing Protocol for Mobile Ad Hoc Networks with Neighbor Awareness and Multicasting”, Pro-ceedings of IEEE E-Tech, July, 2004, pp. 97-100.

[32] Lim, H. and Kim, C., "Multicast Tree Construction and Flooding in Wireless Ad Hoc Net-works", Proceedings of the 3rd ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems, pp. 61-68.

[33] Lin, X. and Stojmenovic, I., "GEDIR: Loop-Free Location Based Routing in Wireless Net-works", Proceedings of the IASTED International Conference on Parallel and Distributed Computing and Systems, 1999, pp. 1025–1028.

[34] Ko, Y.-B. and Vaidya, N. H., "Location-Aided Routing (LAR) in Mobile Ad Hoc Net-works", Wireless Networks, 6 (2000), pp. 307-321.

[35] Karp, B. and Kung, H. T., "GPSR: Greedy Perimeter Stateless Routing for Wireless Net-works", ACM MOBICOM 2000, pp. 243-254.

[36] Liao, W.-H. , Tseng, Y.-C., Lo, K.-L., and Sheu. J.-P., “GeoGRID: A Geocasting Protocol for Mobile Ad Hoc Networks based on GRID”, Journal of Internet Technology, 1(2), 2000, pp.23-32.

[37] Jain, R., Puri, A., and Sengupta, R., "Geographical Routing Using Partial Information for Wireless Ad Hoc Networks", IEEE Personal Communications, February 2001, pp. 48-57.

[38] Ko, Y.-B. and Vaidya, N. H., “Location-based multicast in mobile ad hoc networks”, Tech-nical Report TR98-018, Texas A&M University, 3, 1998.

[39] Sinha, P., Sivakumar, R., and Bharghavan, V., "MCEDAR: Multicast Core-Extraction Dis-tributed Ad Hoc Routing", Proceedings of IEEE WCNC, Vol. 3, 1999, pp. 1313-1317.

[40] Wu, C. W. and Tay, T. C., "AMRIS: A Multicast Protocol for Ad Hoc Wireless Networks", IEEE MILCOM 1999, Vol. 1, pp. 25-29.

References (Contd.)

[41] Toh, C.-K., Guichal, G., and Bunchua, S., "ABAM: On-Demand Associativity-Based Mul-ticast Routing for Ad Hoc Mobile Networks", Proceedings of IEEE VTS-Fall VTC 2000, Vol. 3, pp. 987-993.

[42] Royer, E. M. and Perkins, C. E., "Multicast Ad Hoc On-Demand Distance Vector (MAODV) Routing", IETF Draft, draft-ietf-manet-maodv-00, 15 July, 2000, available at http://tools.ietf.org/html/draft-ietf-manet-maodv-00

[43] Ji, L. and Corson, M. S., "Differential Destination Multicast-A MANET Multicast Routing Protocol for Small Groups", Proceedings of IEEE INFOCOM 2001, Vol. 2, pp. 1192-1201.

[44] S. Lee, W. Su, and M. Gerla, “On-Demand Multicast Routing Protocol in Multihop Wire-less Mobile Networks”, ACM/Kluwer Mobile Networks and Applications (MONET), vol. 7, no. 6, pp. 441–453, December 2002.

[45] Jetcheva, J. G. and Johnson, D. B., "Adaptive Demand-Driven Multicast Routing in Multi-Hop Wireless Ad Hoc Networks", Proceedings of ACM MobiHoc 2001, pp. 33-44.

[46] Xie, J., Talpade, R. R., Mcauley, A., and Liu, M., "AMRoute: Ad Hoc Multicast Routing Protocol", Mobile Networks and Applications 7, 2002, pp. 429-439.

[47] Das, S. K., Manoj, B. S., and Murthy, C. S. R., "A Dynamic Core Based Multicast Routing Protocol for Ad Hoc Wireless Networks", Proceedings of ACM MobiHoc 2002, pp. 24-35.

[48] Sisodia, R. S., Karthigeyan, I., Manoj, B. S., and Murthy, C. S. R., "A Preferred Link Based Multicast Protocol for Wireless Mobile Ad Hoc Networks", Proceedings of IEEE ICC 2003, Vol. 3, pp. 2213-2217.

[49] Kravets, R. and Krishnan, P., "Power Management Techniques for Mobile Communica-tion", Proceedings of ACM MOBICOM 1998, pp. 157-168.

[50] Quintero, A., Pierre, S., and Macabéo, B., "A routing protocol based on node density for ad hoc networks", Ad Hoc Networks, Volume 2, Issue 3, July 2004, pp. 335-349.

References (Contd.)

[51] Saigal, V., Nayak, A. K., Pradhan, S. K., and Mall, R. "Load balanced routing in mobile ad hoc networks", Computer Communications, Volume 27, Issue 3, February 2004, pp. 295-305.

[52] Wei, X., Chen, G., Wan, Y., and Mtenzi, F., "Optimized priority based energy efficient rout-ing algorithm for mobile ad hoc networks", Ad Hoc Networks, Volume 2, Issue 3, July 2004, pp. 231-239.

[53] Wang, N.-C. and Chang, S.-W., "A reliable on-demand routing protocol for mobile ad hoc networks with mobility prediction", Computer Communications, Volume 29, Issue 1, 1 De-cember 2005, pp. 123-135.

[54] Bür, K. and Ersoy, C., "Ad hoc quality of service multicast routing", Computer Communi-cations, Volume 29, Issue 1, 1 December 2005, pp. 136-148.

[55] Boukerche, A., El-Khatib, K., Xu, L., and Korba, L., "An efficient secure distributed anonymous routing protocol for mobile and wireless ad hoc networks", Computer Communi-cations, Volume 28, Issue 10, 16 June 2005, pp. 1193-1203.

[56] Moaveninejad, K., Song, W.-Z., and Li, X.-Y., "Robust position-based routing for wireless ad hoc networks", Ad Hoc Networks, Volume 3, Issue 5, September 2005, pp. 546-559.

[57] Rango, F. D., Gerla, M., and Marano, S., "A scalable routing scheme with group motion support in large and dense wireless ad hoc networks", Computers & Electrical Engineering, Volume 32, Issues 1-3, January-May 2006, pp. 224-240.

[58] Ghosh, R.K., Garg, V., Meitei, M.S., Raman, S., Kumar, A., and Tewari, N., "Dense cluster gateway based routing protocol for multi-hop mobile ad hoc networks", Ad Hoc Networks, Volume 4, Issue 2, March 2006, pp. 168-185.

[59] Wang, Y.-H. and Chao, C.-F., "Dynamic backup routes routing protocol for mobile ad hoc networks", Information Sciences, Volume 176, Issue 2, 20 January 2006, pp. 161-185.

[60] Ahn, C. W., "Gathering-based routing protocol in mobile ad hoc networks", Computer Communications, Volume 30, Issue 1, 15 December 2006, pp. 202-206.

References (Contd.)

[61] Sun, B. and Li, L. "QoS-aware multicast routing protocol for Ad hoc networks", Journal of Systems Engineering and Electronics, Volume 17, Issue 2, June 2006, pp. 417-422.

[62] Eisbrener, J., Murphy, G., Eade, D., Pinnow, C. K., Begum, K., Park, S., Yoo, S.-M., and Youn, J.-H., "Recycled path routing in mobile ad hoc networks", Computer Communications, Volume 29, Issue 9, 31 May 2006, pp. 1552-1560.

[63] Layuan, L., and Chunlin, L., "A QoS multicast routing protocol for clustering mobile ad hoc networks", Computer Communications, Volume 30, Issue 7, 26 May 2007, pp. 1641-1654.

[64] Lu, R., Cao, Z., Wang, L., and Sun, C., "A secure anonymous routing protocol with authen-ticated key exchange for ad hoc networks", Computer Standards & Interfaces, Volume 29, Is-sue 5, July 2007, pp. 521-527.

[65] Giruka, V. C. and Singhal, M., "A self-healing On-demand Geographic Path Routing Proto-col for mobile ad-hoc networks", Ad Hoc Networks, Volume 5, Issue 7, September 2007, pp. 1113-1128.

[66] Wang, N.-C., Huang, Y.-F., and Chen, J.-C., "A stable weight-based on-demand routing protocol for mobile ad hoc networks", Information Sciences, 2007, In Press.

[67] Yang, C.-C. and Tseng, L.-P., "Fisheye zone routing protocol: A multi-level zone routing protocol for mobile ad hoc networks", Computer Communications, Volume 30, Issue 2, 15 January 2007, pp. 261-268.

[68] Chan-Ho Min and Sehun Kim, "On-demand utility-based power control routing for energy-aware optimization in mobile ad hoc networks", Journal of Network and Computer Applica-tions, Volume 30, Issue 2, April 2007, pp. 706-727.

[69] Song, J.-H., Wong, V. W.S., and Leung, V. C.M., "Secure position-based routing protocol for mobile ad hoc networks", Ad Hoc Networks, Volume 5, Issue 1, January 2007, pp. 76-86.

[70] Reddy, L. R. and Raghavan, S.V., "SMORT: Scalable multipath on-demand routing for mo-bile ad hoc networks", Ad Hoc Networks, Volume 5, Issue 2, March 2007, pp. 162-188.

[71] Zhao, Y., Chen, Y., Li, B., and Zhang, Q., "Hop ID: A Virtual Coordinate-Based Routing for Sparse Mobile Ad Hoc Networks", IEEE Transactions on Mobile Computing, Vol. 6, No. 9., September 2007, pp. 1075-1089.

Thank You!